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Low-Dimensional Quantum Physics Group

http://ldp.phys.tohoku.ac.jp

Academic Staff

Professor	Naoki Toyota
Associate Professor	Hiroshi Matsui
Secretary	Michiko Yamashita
Graduate Students	Momoko Kuno (D3)
	Yasunori Abe (M2)
	Yusuke Ishizaki (M2)
	Eiichi Negishi (M2)
	Takahiko Kuwabara (M1)
	Takahiro Suzuki (M1)
	Toshihiko Naka (M1)

Research Activities

I. Molecular Magnetic Conductors

1. Anomalous Microwave Response in λ-(BEDT-TSF)$_2$FeCl$_4$

(H. Matsui, T. Suzuki and N. Toyota)

The temperature dependence of the microwave conductivity and dielectric function has been observed in λ-(BEDT-TSF)$_2$FeCl$_4$ by a cavity perturbation method at 16.3 and 44.5 GHz. In order to evaluate these values, both the resonant frequency and width are measured as a function of either temperature or magnetic field with and without the sample, the weight of which is few μg used in the measurements. When the microwave electric field is applied parallel to the c axis, we have found that the real part of the dielectric function, ε_1^c, enhances to a positive values on the order of 10^3 from 70 K to the metal-insulator transition temperature, T_{MI} = 8.3 K. In that temperature range, however, the dc resistivity shows a usual metallic conduction. The real part of the microwave conductivity, σ_1^c, becomes resistive below 70 K in contrast to the dc conductivity. The novel dielectric anomaly emerged around 70 K is attributed to the dynamical response of the charge degrees of freedom in the π electronic system. The recent specific heat, ^{1}H-NMR and X-ray measurements also exhibit remarkable anomalies at 70 K. The antiferromagnetic π-d interaction makes some contribution to the anomaly, since any anomaly is not observed in the Ga analogue.

When the microwave electric field is applied parallel to c, the resonance width shows a sharp peak just below T_{MI} due to the crossover from the metallic side to the insulating one in a depolarization regime. The temperature dependence of σ_1^c obtained

by the resonance frequency and width is highly conductive compared to the dc conductivity σ_{dc}^{c}; σ_1^{c} around 2 K is about two orders of magnitude larger than σ_{dc}^{c}. This conductive behavior may be attributed to the low energy excitation inside the gap near the Fermi level, that is, some collective mode. Below T_{MI}, ε_1^{c} is suppressed immediately to the value of ~ 45. The drastic change in ε_1^{c} at T_{MI} could correspond to a charge localization of the π electrons.

2. Non-Linear Dynamical Conductivity in the Antiferromagnetic Insulating States of λ-(BETD-TSF)$_2$FeCl$_4$

(Y. Abe, T. Kuwabara, H. Matsui and N. Toyota)

We have studied the current-voltage *I-V* characteristics in a quasi two-dimensional, π-*d* coupled organic conductor λ-(BEDT-TSF)$_2$FeCl$_4$ which undergoes a metal-to-insulator transition associated with an antiferromagnetic ordering at T_{MI} = 8.3 K. Drastic nonlinear transport phenomena are observed in the *I-V* curve, revealing so-called a negative resistance effect at applied electric field or current density higher than threshold E_T or J_T. Overall *I-V* curves are quite well explained phenomenologically by a nonlinear equation for a positive feedback system that the nonlinear conductivity proportional to J^n with n = 1.4 ($\pm$0.1). It indicates that some carrier decondensation mechanism works in present antiferromagnetic insulator. Discussions are presented by following quite similar nonlinear phenomena observed in a variety of quasi one-dimensional, mixed-stack and segregated-stack organic insulators.

3. Antiferromagnetic Resonance in the Antiferromagnetic Insulating States of λ-(BETD-TSF)$_2$FeCl$_4$

(T. Suzuki, H. Matsui and N. Toyota)

From microwave cavity transmission measurements at 23–110 GHz on λ-(BEDT-TSF)$_2$FeCl$_4$, we have observed an antiferromagnetic resonance (AFMR) in the antiferromagnetic insulating state below the metal-to-insulator transition temperature of T_{MI} = 8.3 K. The frequency-field dependence is fundamentally reproduced with a two-sublattice model for a biaxial anisotropy. The easy axis is confirmed to be the direction tilted by 30° from c to b^*, and the hard axis is found to be close to a^*. The spin-flop field is identified to be 1.3 T through the frequency-field dependence for the easy axis. The AFMR is interpreted to be caused by spin waves excited on the π spins, exclusively due to the large π–π exchange interaction estimated by theoretical calculations. The exchange field and anisotropy fields for π spin systems at 1.2 K are evaluated to be H_E~330 T, H_A^1~1.5×10^{-3} T for the intermediate axis and H_A^2~5.0×10^{-3} T for the hard axis, respectively.

4. Microwave Conductivities in Non-Magnetic Metal λ-(BEDT-TSF)$_2$GaCl$_4$ and Mixed Salt λ-(BEDT-TSF)$_2$Fe$_{0.45}$Ga$_{0.55}$Cl$_4$

(Y. Ishizaki, T. Suzuki, E. Negishi, H. Matsui and N. Toyota)

We have found that the anomalous metallic state forms at $T_{MI} < T < 70$ K in λ-(BEDT-TSF)$_2$FeCl$_4$. In order to investigate a contribution of π–d interaction to the anomalous metallic state, we have measured the microwave conductivities in the mixed systems. In $GaCl_4$ salt, we have observed a peak just below the superconducting transition temperature ~ 5 K. The peak is expected to be a coherence peak, and thus the superconducting symmetry could be a s-wave.

II. Magnetic and Transport Properties in a Mesoporous Carbon CMK-1

(M. Kuno, T. Naka, E. Negishi, H. Matsui and N. Toyota)

The magnetic susceptibility of the mesoporous CMK-1 follows a Curie-Weiss law at high temperatures. Around 4 K, the magnetic susceptibility shows a peak, and a remarkable hysteresis has been observed below 10 K. This result is reminiscent of a spin-glass behavior. The temperature dependence of the electrical resistivity is proportional to $\exp(T^{-1/3})$ in low temperature range, which may reveal a two-dimensional variable range hopping. Now we are studying variations of the electrical and magnetic properties through doping alkaline atoms such as K.

III. Developments of Microwave and Hyper-Ultrasonic Apparatus

1. Microwave Conductivity Measurements Based on a Cavity Perturbation Method

(H. Matsui, H. Suzuki and N. Toyota)

We have developed the scalar type microwave system to measure a dynamical response of electronic systems to a high-frequency electromagnetic wave. The microwave experiments are based on a cavity perturbation method with cylindrical cavity. Small input power and large dynamic range are successfully realized in our apparatus. Furthermore, the experimental configuration can be easily changed to measure the cyclotron resonance and electron spin resonance. We apply our microwave system to study the high-frequency complex conductivity, dielectric constant and permeability in organic conductors and strongly correlated electron systems.

2. Hypersonic Measurements at Microwave Frequency Range

(E. Negishi, H. Matsui and N. Toyota)

We have constructed a hypersonic system to measure sound absorptions in microwave frequency range of low dimensional electronic systems with strong correlations. The excitation and detection of hypersonics are too difficult to realize, so that only a few studies have been reported on a hypersonic absorption of solids. Our group possesses both ultrasound and microwave techniques, which are fundamentally required to build up the hypersonic system. We have developed reentrant cavities with high Q values made of an oxygen free copper to generate and detect hypersonics. Most difficult thing is to control precisely the resonant frequency of the cavity, because the

frequency varies with temperatures. A huge amount of times were necessary to develop the control mechanisms. Finally we achieved the frequency control by changing cavity volumes with three manipulators mounted on a top flange of the insert at room temperature. The electric circuits are based on a super-heterodyne detection to increase resolution. We have carried out longitudinal hypersonic measurements of single crystal quartz with 1 cm on length. First and second echo signals were successfully detected, and the temperature change of the absorption coefficient was identified to follow T^3 dependence. We continue studying the hypersonic absorption of organic materials to elucidate the dynamics of low dimensional electrons.

Publications

1) "Antiferromagnetic Resonance in λ–(BEDT-TSF)$_2$FeCl$_4$", T. Suzuki, H. Matsui, H. Tsuchiya,E. Negishi, K. Koyama and N. Toyota, Phys. Rev. B **67** (2003) 020408(R).

2) "Dielectric Response in the Metallic States of λ–(BEDT-TSF)$_2$FeCl$_4$", H. Matsui, H. Tsuchiya, H. Uozaki, Y. Abe, Y. Ishizaki, E. Negishi, S. Endo, N. Toyota, Synth. Met. **133-134** (2003) 559-560.

3) "Microwave Response in the Antiferromagnetic Insulating States of λ–(BEDT-TSF)$_2$FeCl$_4$",H. Tsuchiya, H. Matsui, H. Uozaki, Y. Abe, Y. Ishizaki, E. Negishi, S. Endo, N. Toyota, Synth. Met. **133-134** (2003) 561-562.

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6) "Specific Heat Studies for λ–(BEDT-TSF)$_2$FeCl$_4$", E. Negishi, H. Uozaki, Y. Ishizaki, H. Tsuchiya, S. Endo, Y. Abe, H. Matsui, N. Toyota, Synth. Met. **133-134** (2003) 555-556.

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10) "Evidence of the First-Order Nature of the Metal-Insulator Phase Transition in λ–(BEDT-TSF)$_2$FeCl$_4$", M. Watanabe, S. Komiyama, R. Kiyanagi, Y. Noda, E. Negishi and N. Toyota, J. Phys. Soc. Jpn. 72 (2003) 452-453.

11) 「準２次元導体 λ-(BEDT-TSF)$_2$FeCl$_4$ における異常金属状態 －マイクロ波伝導・誘電異常－」、豊田直樹、松井広志、日本物理学会誌、**57** (2002) 575-580.

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Master Theses (March, 2003)

M1) Yasunori Abe

Dielectric Response and Nonlinear Conduction in π-d Mott Insulator λ-(BEDT-TSF)$_2$FeCl$_4$

M2) Yusuke Ishizaki

Microwave Response in the Superconducting State of Quasi Two Dimensional Organic Conductor λ-(BEDT-TSF)$_2$GaCl$_4$

M3) Eiichi Negishi

Construction of Hypersonic Measuring System